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SPH-4 U.S. Army Flight Helmet Performance 1972-1983

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Crushable Earcups		ALSERP

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20. ABSTRACT

Injury data was obtained from the US Army Safety Center for the occupants of US Army aircraft who were both wearing aviator helmets and involved in duty-related aircraft accidents from the period beginning on 1 January 1972 and ending on 31 December 1982. The injury data was correlated with the physical condition of the helmets involved which had been obtained by the US Army Aeromedical Research Laboratory under the Aviation Life Support Equipment Retrieval Program. The helmet performance was evaluated with regard to current injury prevention capabilities and potential improvements for future helmet designs. For consistency, only the 208 SPH-4s in the data base were fully analyzed. An appendix contains a limited analysis of the APH-5s performance. It should be emphasized that no combat damaged helmets are discussed or analyzed in this report; i.e., no shrapnel or bullet damage is covered.

ACKNOWLEDGEMENTS

The writers acknowledge the dedicated effort expended by the USAARL computer staff, Dr. Heber Jones and Mr. Alford A. Higdon, Jr., in the final programming of the data presented in the tables. Appreciation is also extended to Mr. Darrick Bradford for his initial contribution to the data reduction effort.

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INTRODUCTION

In 1972, the US Army Aeromedical Research Laboratory (USAARL) established the Aviation Life Support Equipment Retrieval Program (ALSERP). The purpose of this program is to evaluate the effectiveness of protective equipment in the aircraft accident environment and to contribute to the improvement of this equipment through modification or development of new design criteria. Army Regulation 95-5 (chapter 10, paragraph 10-13, page 10-19), and Department of the Army Pamphlet 385-95 (page 5-6, paragraph 6) requires all life support equipment which is in any way implicated in the cause or prevention of injury to be shipped to this laboratory for analysis. This report summarizes the findings of 208 Sound Protection Helmet No. 4 (SPH-4) items which have been analyzed in the ALSERP from 1972 through 1982. In addition, a total of 14 Aviator Protective Helmet No. 5 (APH-5) items are separately analyzed and included in Appendix A. This paper will only analyze noncombat injuries due to the forces experienced during the accident sequence (i.e., there are no bullet or shrapnel injuries in the study).

METHODS AND MATERIALS

The Army's standard flight helmet, SPH-4, replaced the Navy-developed APH-5 in the 1970-1973 period and has been in continuous use since. Components and features of the SPH-4 are shown in Figures 1, 2, and 3.

Pertinent features of the SPH-4 are:

1. Shell - 2.5mm thick epoxy resin and fiberglass cloth.

2. Liner - Energy-absorbing 1.3 cm thick expanded polystyrene with a density of 0.08 gm/cm^3.

3. Suspension - With two standard shell sizes, the adjustable headband and crown straps provide easy fitting for most wearers.

4. Earcups - Large "rotatable" design provides easy fit and excellent noise attenuation.

5. Acoustic Sealing - Tension cross straps in the shell provide inward pressure on earcup seals for excellent sealing and easy fit for most wearers.

6. Ventilation - Natural air circulation occurs above the head as shown in Figures 1, 2, and 3.

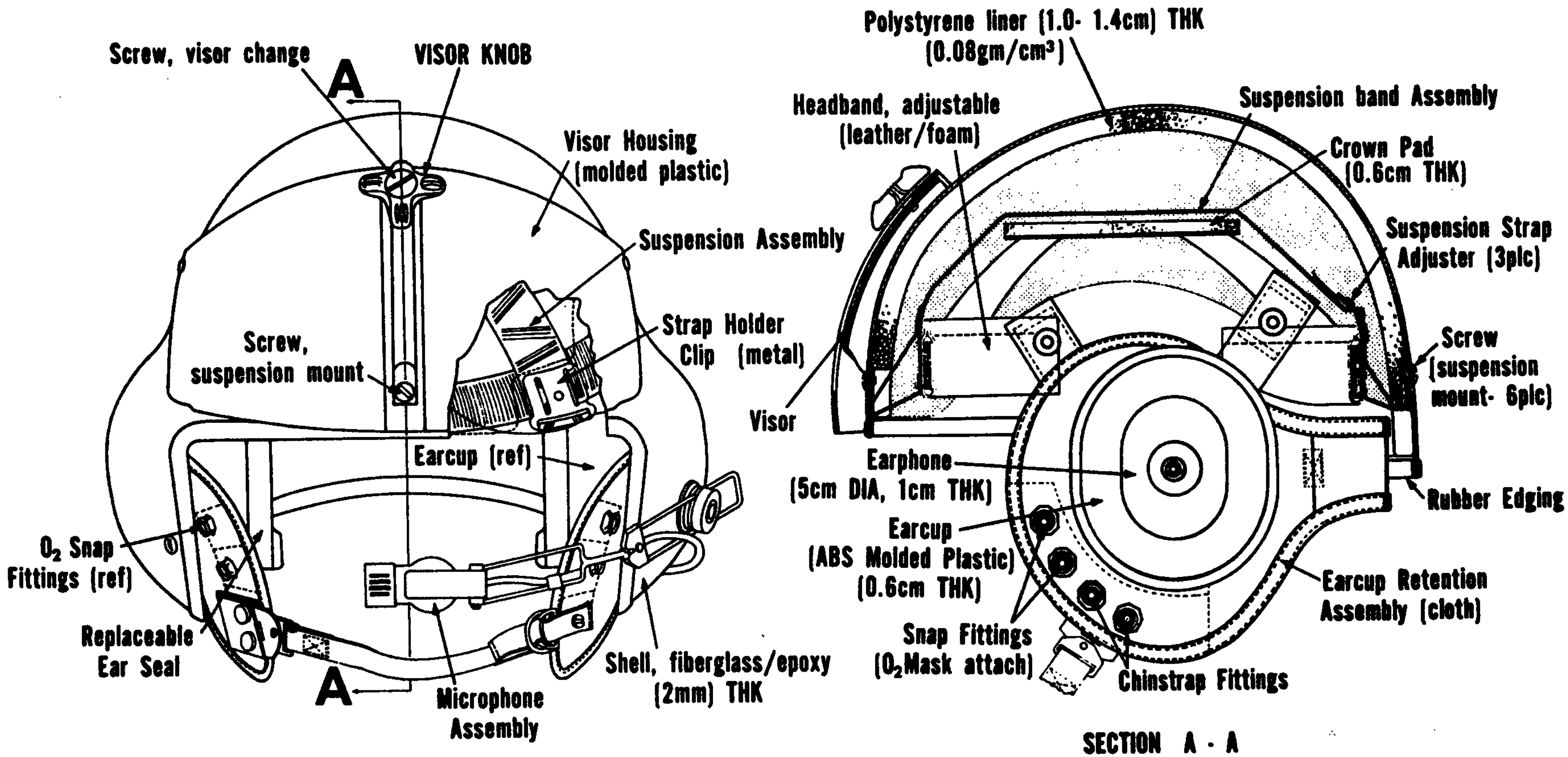

FIGURE 1. SPH-4 Helmet Assembly.

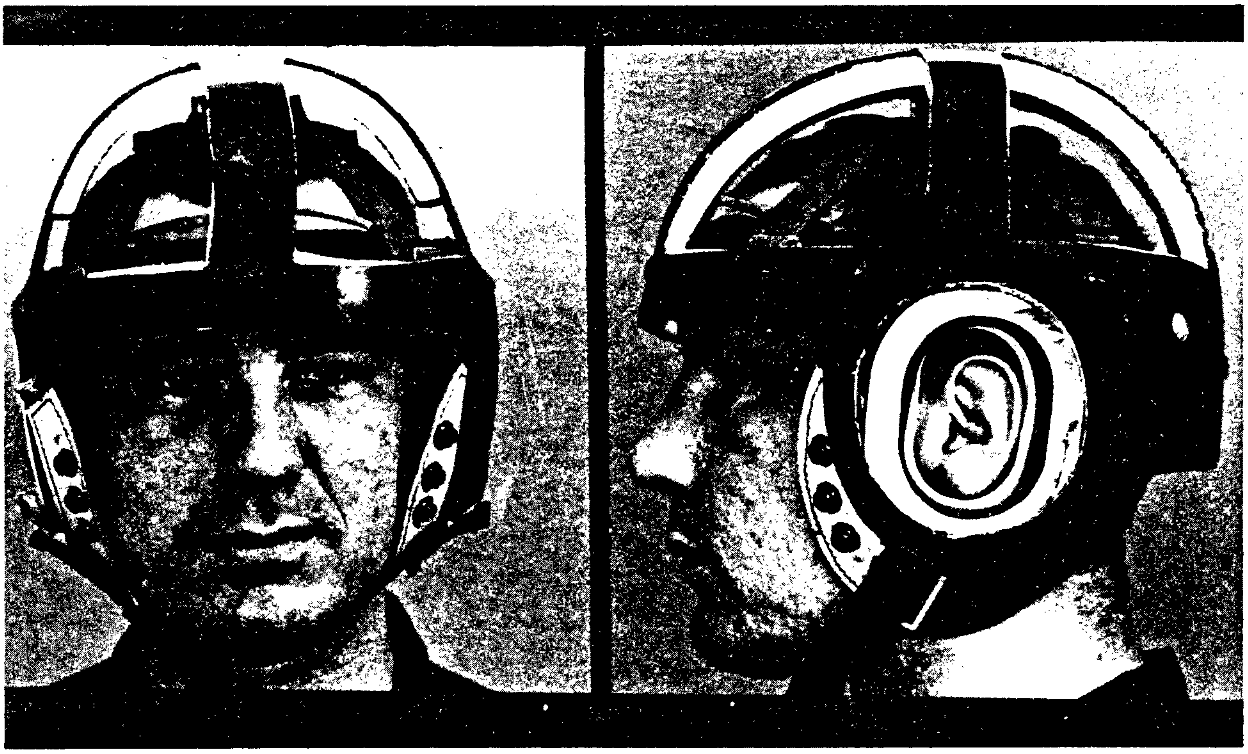

FIGURE 2. Front and Profile Views of Cutaway SPH-4.

FIGURE 3. Liner Coverage Provided by SPH-4.

The SPH-4, with good fit made possible by the adjustable earcups and sling suspension, provides outstanding noise attenuation, especially against low frequency noise (Bynum, 1968). The quality of the SPH-4 is controlled by military drawings, specifications, and standards MIL-H-43925 (Department of the Army, 1975). In addition, the acoustic, impact, and retention characteristics of the helmet are verified for each new procurement lot.

HELMET ANALYSIS

The analyses in the main body of the report are confined to the SPH-4. A short review of the data from the 14 APH-5 helmets collected in this study are included in Appendix A.

A total of 208 SPH-4s have been analyzed from 112 aircraft accidents which occurred from 1 January 1972 through 31 December 1982. Only 4 of these helmets were from fixed wing (OV-1 Mohawk) aircraft. The rest were from rotary wing accidents. Table 1 shows the origin of the helmets by aircraft and seat location.

Each helmet was analyzed by USAARL's Aviation Life Support Equipment Inspection Team which included engineers, a flight surgeon, an aerospace physiologist, and a life support equipment specialist. This team conducted a thorough review and analysis of each case and was responsible for completion of the data collection form shown in Appendix B.

The form is intended to record data in four areas:

1. General information about the accident (questions 1-5, 9, and 10).

2. Information about the helmet and its performance (questions 6-8, 14-18, 20, 21, 27, and 28).

3. Information concerning the aviator's injuries (questions 11-13, and 19).

4. Damage to the various helmet components and causes of such damage (questions 22-26, 29, and 30).

Data for areas 1, 2, and 3 usually were obtained by reviewing the official report of each accident, DA Form 2397, "Technical Report of US Army Aircraft Accident." When necessary, the inspection team would communicate directly with medical personnel or other investigators who were involved in a particular accident. All head injuries were graded according to severity using the "Abbreviated Injury Scale" (AIS) as a guide

(Joint Committee of the American Medical Association, 1976). The AIS system was used to quantify a broad range of head injuries into categories of varying severity. A summary of this scale is shown in Table 2.

In 1980, the Joint Committee published an updated AIS system which made significant changes in the method of coding head injuries. Because the majority of our data was collected and coded using the earlier system, it was elected to continue using it in our current analysis. Future studies in our continuing ALSERP data collection will use both systems in order to keep up with the most modern evaluation techniques while allowing us to refer to the current data base findings for comparison.

TABLE 1
AIRCRAFT IDENTITY AND HELMET WEARER SEAT LOCATION

BREAKDOWN OF HELMETS BY TYPE AND MODEL OF AIRCRAFT		LOCATION OF SPH-4 WEARER IN THE AIRCRAFT	
UH-1	115	PILOT OR COPILOT	157
AH-1	22	LEFT PASSENGER	19
OH-58	45	MIDDLE PASSENGER	13
CH-47	8	RIGHT PASSENGER	14
OV-1	4	UNKNOWN	5
TH-13	2	TOTAL	208
TH-55	4		
OH-6	4		
CH-54	4		
TOTAL	208		

Each helmet wearer was placed into one of three categories based on head injury and helmet performance. The survivable category consisted of those individuals who had either no head injuries or nonfatal head injuries. Individuals with fatal injuries were placed in either the nonsurvivable category or the potentially survivable category.

Potentially survivable head injury cases were those in which the inspection team was convinced that an improved helmet of feasible design (generally one with improved energy absorption and retention capability) would have lessened or prevented the individual's injury and thus prevented the fatality. Nonsurvivable cases were those in which it was determined that no feasible improvement in the helmet would have been of benefit to the wearer under the circumstances of the accident. It is the survivable and potentially survivable cases which are most productive for suggesting performance changes for future helmets.

TABLE 2
SUMMARY OF ABBREVIATED INJURY SCALE CODES*

0	NO INJURY	
1	MINOR	(No unconsciousness; nasal fracture, superficial scalp lacerations, dizziness, headache)
2	MODERATE	($\leq$ 15 min unconsciousness; linear fracture, inner ear injury with deafness or vertigo, retinal detachment, deep scalp laceration)
3	SEVERE	($\geq$ 15 min unconsciousness; eye avulsion, orbit fracture, ethmoid fracture)
4	SERIOUS	(Unconscious < 12 hrs with neurological deficit; life threatening)
5	CRITICAL	(Unconscious > 12 hrs with neurological deficit; survival uncertain)
6	MAXIMUM	(Currently untreatable, partial or complete decapitation, crushed skull)

*The Abbreviated Injury Scale.

HELMET DAMAGE EVALUATION

Each helmet was examined externally and internally at USAARL to determine the number, severity, and location of all impacts due to the accident. Impacts were defined as any contact of the external shell of the helmet with environmental objects sufficient to cause either external surface changes, compression of underlying foam, or both during the course of the crash sequence.

Helmet damage was cataloged according to location, type of shell damage, approximate amount of foam compression, and shape of impact surface.

1. Location. The helmet was divided into five large areas: crown, front, rear, left, and right sides (Figure 4). These five areas were further subdivided as indicated in Appendix B. (The smaller subdivisions were not used in the current analysis.) As many as five impacts per helmet were cataloged by location in these five areas.

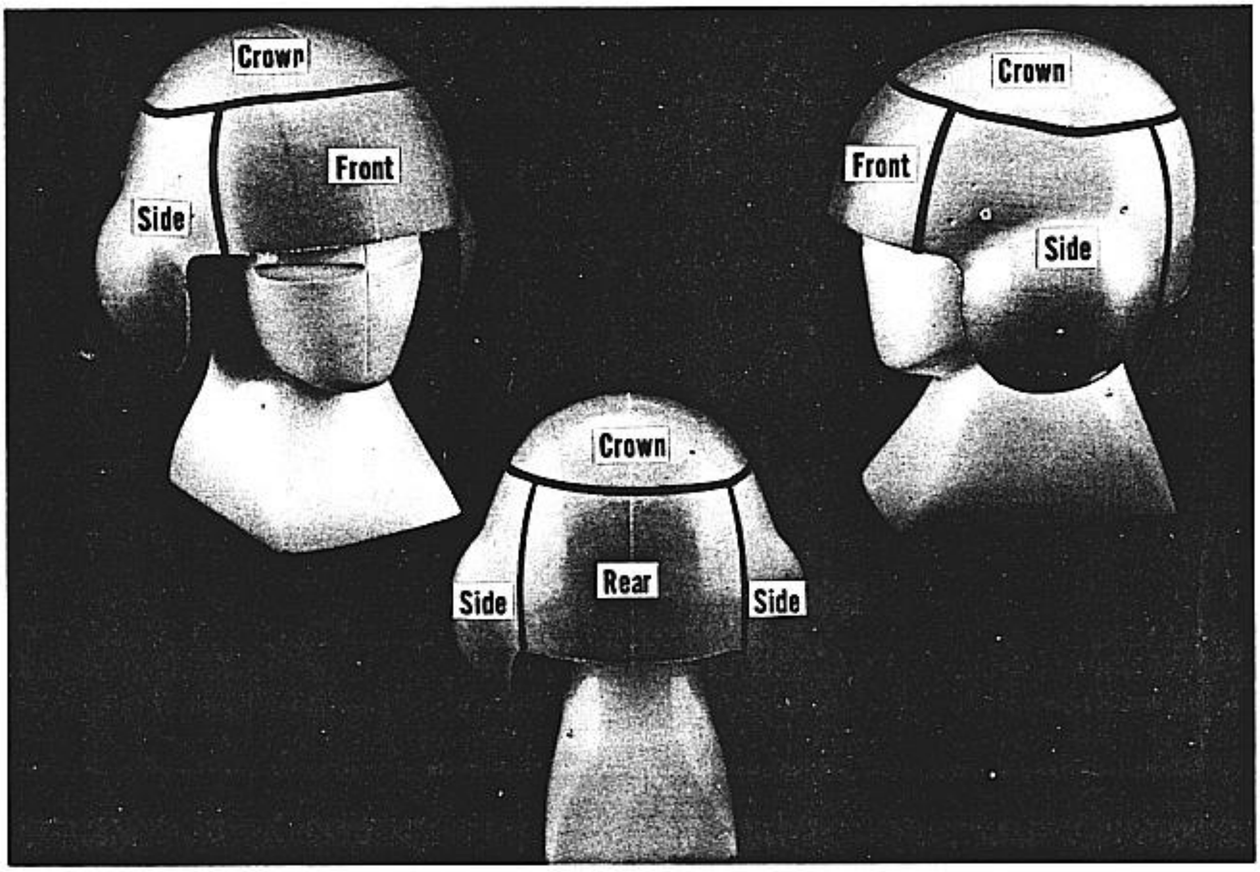

FIGURE 4. Division of Helmet to Determine Impact Location.

2. Shell Damage. Shell damage was recorded qualitatively for each impact area. Damage was described using the following terms:

    1. Fracture: Helmet shell was broken through (severed or separated).

    2. Puncture: A small shell puncture with evidence of a sharp object penetrating through the helmet.

3. Material Missing: Shell material was torn out, usually due to extreme deformation or tangential impacts.

4. Delamination: Shell laminae separated; i.e., the cement binder between the cloth piles failed. This is indicative of considerable inbending which causes shear stresses between laminae. Foam was always compressed beneath a delaminated area.

5. Gouge: A thin deep section of paint and shell carved out by a sharp object.

6. Abrasion: A wide portion of shell worn away due to dragging across a rough surface.

7. No damage: No damage of any consequence to the shell, but evidence of impact pressure to the surface exists (e.g., paint scraped or discolored; traces of the substance of the impact surface are present).

3. Foam Compression. Foam Compression was determined with a measuring device as shown in Figure 5. Areas of compression were measured and the maximum amount of compression was recorded for each impact. Earlier work (Slobodnik and Nelson, 1977) had shown that the liner tended to rebound after compression so that the final thickness was rarely greater than 40 percent of the uncompressed thickness after 72 hours. This was true even if the initial compression had been greater than 90 percent. Since most of our helmets were shipped to us at least one week after the accident (at the earliest) any residual foam compression in our ALSERP material which exceeded 50 percent was considered a maximal compression.

4. Shape of Impact Surface. Impact surfaces were described as one of the the following:

1. Flat: Consisting of a roughly planar surface.

2. Concave: Having a hollowed-out and rounded surface. This is typical of impacts with aluminum sheet metal surfaces which mold to the shape of the helmet such as the roof of the aircraft.

3. Rod: A cylindrical object of 3 cm or more in diameter encountered perpendicular to its axis.

4. Box Corner: A three-sided, pyramid-shaped surface encountered roughly at its apex.

5. Wedge: A surface approximating the intersection of two planes encountered roughly along the line of intersection of the planes.

6. Hemisphere: A nearly spherical or rounded surface with a radius of 5 cm or more encountered roughly perpendicular to its surface curvature.

7. Unknown: A surface which did not puncture the helmet shell and which inflicted blunt damage that was indeterminate between that seen with the flat and concave types of impact surfaces.

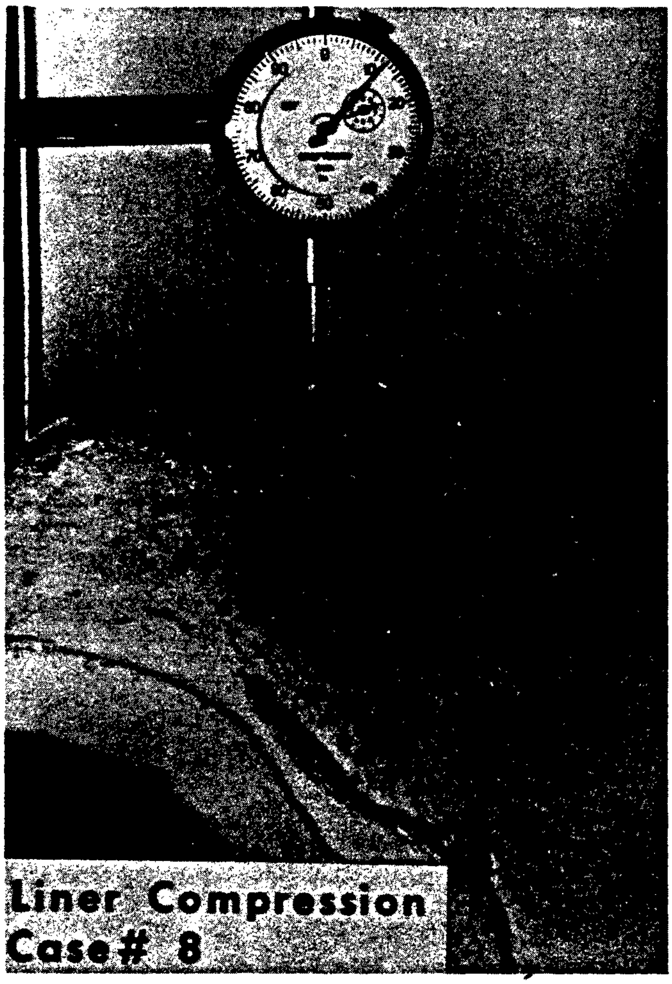

FIGURE 5. Dial Gage Arrangement to Measure Foam Thickness.

RESULTS

In all, 208 SPH-4 units were reviewed along with the injury records of their users. Of these cases, 103 were survivable, 48 were potentially survivable and 57 were nonsurvivable. There were 170 cases of injury to the head, face, or neck. Of these, 117 cases involved only injury to the areas of the head covered by the helmet shell with no facial or neck trauma. Responses to questions 11 D and E indicate that in 82 of the 208 cases (39.4 percent) the users would have received less severe injuries with an improved helmet. (See Table 3.)

TABLE 3
FEATURES IDENTIFIED AS POSSIBLE IMPROVEMENTS

FACTOR	NO. OF TIMES IDENTIFIED
Increased energy absorbtion in liner	52
Stronger chinstrap fastener	27*
Energy-absorbing earcup	24
Improved retention system	16
Improved facial protection	13
Increased puncture resistance	1

* An improved fastener system was implemented in 1978 which has eliminated the problem of helmet loss due to fastener failure.

The distribution of head injuries in terms of severity on the AIS system is depicted in Figures 6 and 7. AIS values range from zero (no injury) to six (currently untreatable; usually fatal). All AIS values of three or more are considered life threatening.

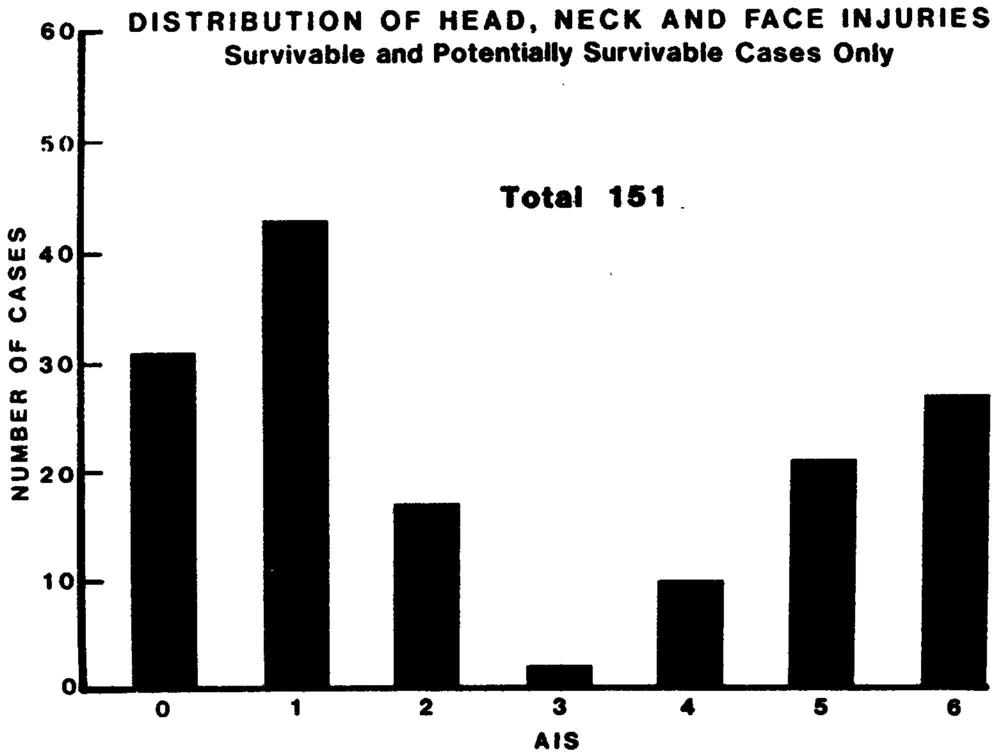

FIGURE 6. Distribution of Head, Neck, and Face Injuries*.
*Survivable and Potentially Survivable Cases.

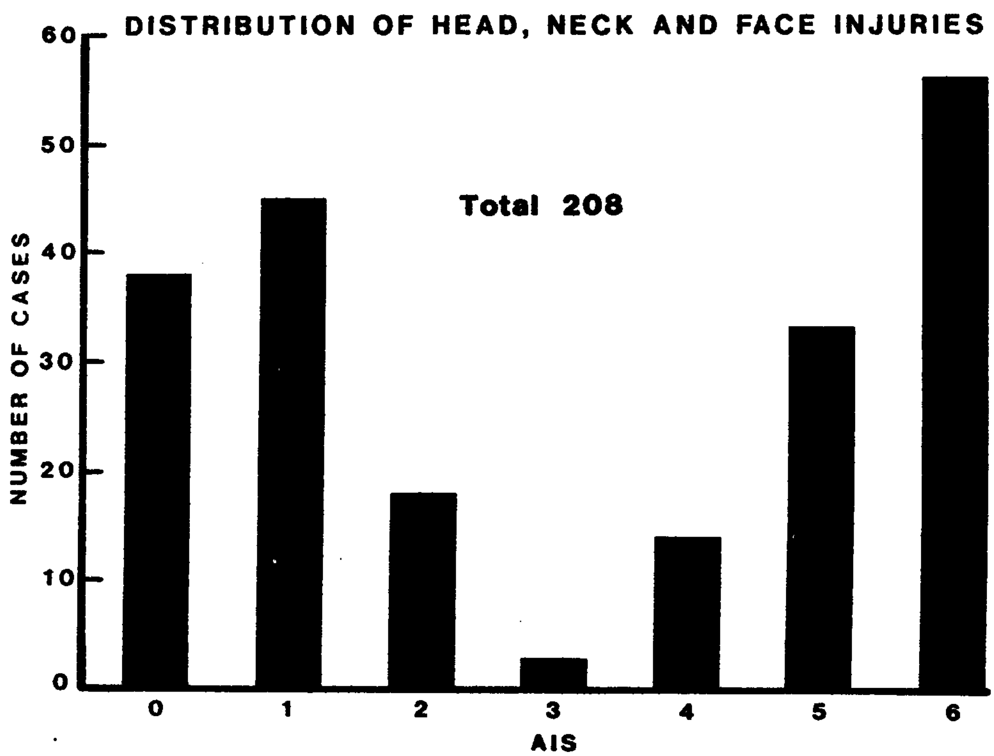

FIGURE 7. Distribution of Head, Neck, and Face Injuries**.
**All Cases.

Of all 208 helmets, 43 (20.6 percent) came off the wearer's head during the crash sequence. In 27 of these cases (62.7 percent) the chinstrap fastener unsnapped under loading. In 16 cases (37.3 percent) the retention assembly failed either by tearing away from the shell, rotating forward over the head due to chinstrap slack and excessive chinstrap stretch, or primary failure of the fabric under stress. These data will receive further analysis in a future report. The causes of the helmet losses are listed in Table 4. An evaluation of 32 survivable and potentially survivable cases reveals an average AIS score of 4.3 for those who lost their helmet versus an average AIS score of 2.7 for all survivable and potentially survivable cases.

TABLE 4
CAUSES OF 43 HELMET LOSSES (SPH-4)*

Retention system failure	34
Chinstrap fastener failure	27
Improper wear (i.e., strap not fastened, etc.)	6

* More than one cause applies to some losses.

Table 5 shows that in survivable and potentially survivable accidents 24 percent of the cases in which the helmet was retained received no injury as opposed to only 5 percent when the helmet was lost. Severe injury resulted to 25 percent of the helmet retained group, versus 67 percent for the helmet lost group.

TABLE 5
HEAD INJURY RELATED TO HELMET RETENTION (SPH-4)*

HELMET STATUS	AIS CODE				TOTAL
	NONE (AIS 0)	MILD (AIS 1-2)	MODERATE (AIS 3-4)	SEVERE (AIS 5-6)	
LOST	1 (5%)	2 (10%)	4 (19%)	14 (67%)	21 (100%)
RETAINED	30 (24%)	56 (45%)	8 (6%)	31 (25%)	125 (100%)
UNKNOWN	0 (0%)	2 (40%)	0 (0%)	3 (60%)	5 (100%)
TOTAL	31 (20%)	60 (40%)	12 (8%)	48 (32%)	151 (100%)

*Nonsurvivable cases excluded.

Two comparisons were made regarding fatality rates and the position of the visor at the time of the accident (Table 6). One included all 208 cases, while the other was limited to the 91 cases with facial injuries. The results in both analyses indicated a 47 percent fatality rate whenever the visor was not being utilized. When the visor was being used, the fatality rate became 29 percent for all cases and 19 percent for cases involving facial injuries.

TABLE 6
FATALITY COMPARED TO VISOR POSITION

Visor Position	All Cases		Facial Injury Cases	
	Fatalities	Total	Fatalities	Total
UP*	40 (47%)	86 (100%)	20 (47%)	43 (100%)
DOWN	10 (29%)	35 (100%)	3 (19%)	16 (100%)
UNKNOWN	55 (63%)	87 (100%)	22 (69%)	32 (100%)
TOTAL	105 (50.5%)	208 (100%)	45 (49.5%)	91 (100%)

* In the "up" position, the visor does not protect the face.

Table 7 shows the frequency of impacts for the helmets in the study associated with survivable and potentially survivable cases. A single impact was most frequently observed (40 percent). Most of the helmets with two or more impacts usually had one major impact with one or more less severe impacts.

TABLE 7
NUMBER OF IMPACTS PER HELMET (SPH-4)*

NUMBER OF IMPACTS	NUMBER OF HELMETS	PERCENT OF TOTAL
0	16	11%
1	61	40%
2	40	27%
3	18	12%
4	14	9%
5	2	1%
TOTAL	151	100%

* Nonsurvivable cases excluded.

Six helmets had evidence of shell puncture. Only one was considered survivable. The other five were considered nonsurvivable by the inspection team; no helmet of reasonable design using military standards and current state-of-the-art technology would have protected the aviator from the sharp edged, rigid object which the helmet struck.

Table 8 lists the various shapes of impact surfaces for the most severe impact for each helmet and the frequency of occurrence versus the severity of the damage sustained. Flat surfaces were the most frequently encountered impactors (60 percent).

TABLE 8
IMPACT SURFACE OF THE MOST SEVERE IMPACT*

Impact Surface Shape	AIS 0	1	2	3	4	5	6	Total Impact #	Percent of Total	Average AIS
Flat	11	27	10	0	5	11	17	81	60.00%	2.77
Rod	0	2	3	0	2	2	4	13	9.63%	3.84
Concave	1	2	1	1	1	1	1	8	5.93%	2.75
Box Corner	0	3	1	0	0	2	2	8	5.93%	3.38
Wedge	4	0	1	0	0	0	0	5	3.70%	0.40
Hemisphere	1	0	0	0	0	1	1	3	2.22%	3.67
Unknown	6	4	0	0	2	3	2	17	12.59%	2.29
TOTAL	23	38	16	1	10	20	27	135**	100.00%	2.77

* Nonsurvivable cases excluded; ** 16 helmets had no impacts.

Impact location was recorded for the most severe impact on each helmet as shown in Table 9. Although the frontal area is the smallest in surface area (204 cm^2), it received the second highest total number of impacts and had the highest density of impacts per unit area. The sides had the highest total number of impacts, but the impact density was only 37.6 percent of the density of frontal impacts while the average AIS for this area was the highest of the four locations.

TABLE 9
LOCATION OF MOST SEVERE IMPACT*

LOCATION	TOTAL IMPACTS (#)	SURFACE AREA (sq. cm)	IMPACTS PER UNIT AREA (sq. cm)	AVERAGE AIS
CROWN	35	411	0.085	2.71
FRONT	43	204	0.210	1.95
SIDES	49	614	0.079	3.51
REAR	8	226	0.035	3.00
NO IMPACT TO HELMET	16	-	-	1.87
TOTAL	151	1455	0.104	2.58

* Nonsurvivable cases excluded.

The relationship between foam compression at the site of the most severe impact and the head injury sustained by the wearer is shown in Table 10. Only in 11 of these cases (8.1 percent) was the foam close to having been fully utilized (>50 percent compression.) There were 15 cases involving AIS 5 and 6 injuries in which there was 10 percent or less foam compression in the examined helmets. These cases involved helmet losses in which the major injury occurred after the helmet had come off.

TABLE 10
FOAM COMPRESSION AND HEAD INJURY*

	Percent Foam Compression							
	0%	1-10%	11-20%	21-30%	31-40%	41-50%	>50%	TOTAL
AIS								
0	8	12	3	0	0	0	0	23
1	13	16	1	3	2	3	0	38
2	2	7	1	2	2	1	1	16
3	0	0	0	0	1	0	0	1
4	1	1	1	1	2	2	2	10
5	4	4	1	3	3	3	2	20
6	7	0	3	2	1	8	6	27
TOTAL	35	40	10	11	11	17	11	135**

* Nonsurvivable cases excluded; ** 16 helmets had no impacts;

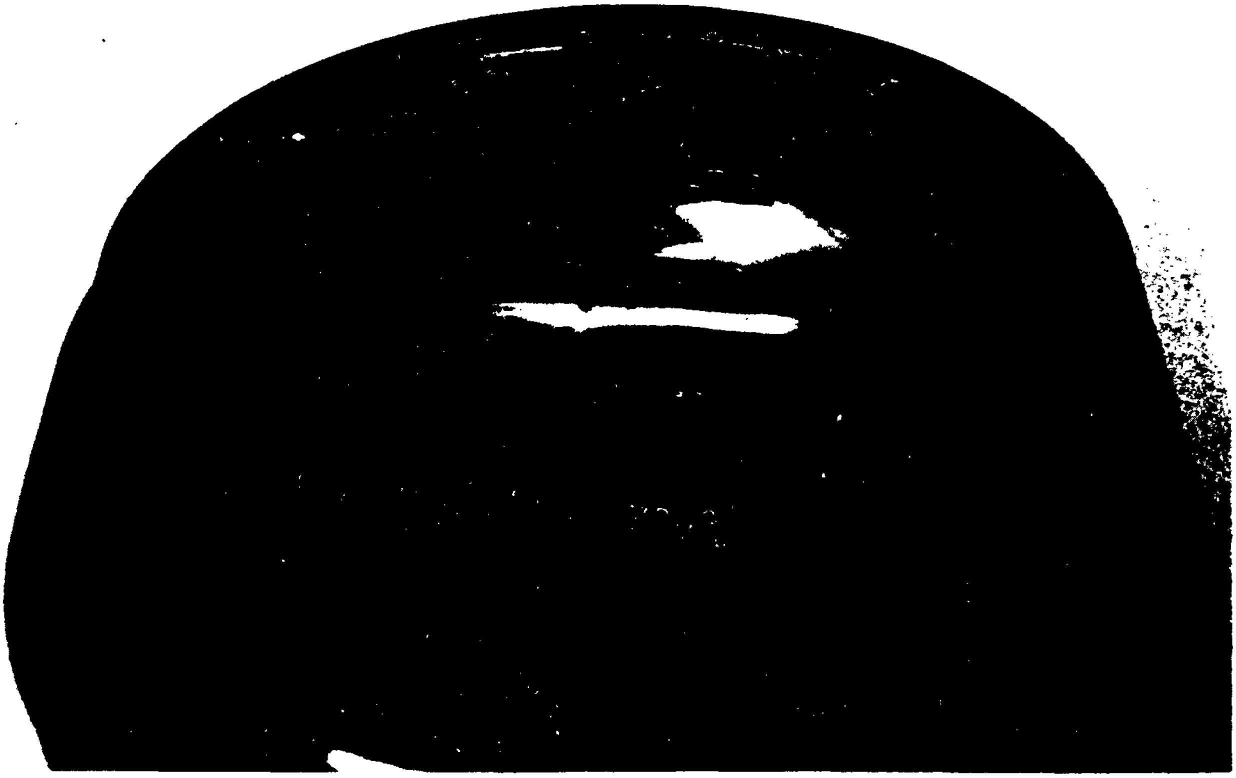

FIGURE 8. Example of Damaged Earcup.

Forty-two cases of earcup damage were noted, and only four of these cases had AIS values below five. Figure 8 depicts representative earcup damage. Thirty of the 42 cases (71.4 percent) were considered survivable or potentially survivable. In 18 of these cases, all circumstances indicated that an energy-absorbing earcup would have lessened the severity of the injuries sustained.

DISCUSSION

Our sample of 208 helmets includes 170 cases involving head, face or neck injuries for the time period from 1 January 1972 through 31 December 1982. For the same period, a review of US Army Safety Center data indicates that a total of 340 cases involving head, neck or face injuries occurred in aviation mishaps. This report reviews 50 percent of all aviation related head, face, and neck injuries which occurred during this period. Our experience with this collection is that helmets involved in more severe injuries were more likely to be sent than those in which little or no human injuries or equipment damage occurred. Despite such cautions, our opinion is that this data base is large enough to allow us to make valid inferences regarding SPH-4 performance.

We believe that in one-third of the cases the level of injury could have been lessened if the helmet had improvements in one or more of the features identified in Table 3. The first four of these features are to be improved in the new integrated flight helmet which the Army currently has under development.

Twenty-one percent of the helmets we received were not retained on the wearer's head at the time of impact. Individuals who lost their helmets sustained significantly more severe head injuries than those who retained their helmets, but this data may be misleading for several reasons. Helmets lost at impact were easily identified by on-the-scene investigators and were highly likely to be sent to USAARL for analysis. This might artificially inflate our helmet loss rate. One would expect the injury severity for those who lost helmets to be higher not only because they lost their helmets, but also because the impact causing such a loss was likely to be quite severe compared with impacts not causing helmet loss.

In the middle of the 1970s, USAARL recognized the problem of chinstrap fastener failure causing helmet loss. Then the issue chinstrap had a single snap fastener on each side and was designed to withstand a 150-pound pull before the snaps failed. In 1978, this was replaced with the double-Y chinstrap incorporating two snaps on each side with a 250-pound failure limit. The current issue chinstrap is fixed to the retention harness on one side and has two snaps on the other side with a 300-pound failure limit. Since the introduction of the modified 2-snap chinstrap in 1978, there have not been any helmet losses due to chinstrap fastener failure alone. This improved performance should be noted when reviewing helmet retention data over the entire time period of the study, and also when reviewing the list of possible improvements in Table 3.

As shown in Table 6, a substantial decrease in the percentage of fatalities exists when the visor is properly utilized. This was true whether or not facial injuries were involved. Unfortunately, only 29 percent of the helmet wearers in this study were known to be properly using their visors at the time of the accident. In view of our results, we strongly urge that the visor be used at all times during flight operations. We recognize that this is not possible with the current Night Vision Goggle (NVG) system or with some of our current and projected target aquisition equipment. Other measures to protect the face from impact injury in the form of padding or inherent crushability should be designed into future NVG and sighting prototypes.

The original acrylic visor was replaced with a more substantial polycarbonate model in 1975. Since only 25 lots of SPH-4s (i.e., 25,000 helmets) were issued with the acrylic visor while more than 80,000 SPH-4s were issued with the polycarbonate visor, the vast majority of visors in this sample from the period after 1975 were probably polycarbonate. Unfortunately, the exact ratio of acrylic to polycarbonate visors was not recorded in this study. All subsequent helmets collected under ALSERP will have this feature duly noted. The helmets previously collected will be reviewed in the future to determine this ratio and relate the type of visor to the injuries suffered by the wearer in a future report.

Flat surfaces were the most frequent impactors (60 percent) and should be considered the primary threat with regard to surface impacts. A cylindrically-shaped surface (i.e., rod) was next in frequency at 9.63 percent. This is followed in frequency by the concave surface which causes a greater transmitted acceleration and force to the head than the flat surface due to the larger area of foam under compression. Next came the box corner, wedge, and hemisphere surfaces, respectively. In all, 21.48 percent of the impacts were from surfaces other than the flat or concave type and nearly half of these were rod-shaped. These represent the most likely noncombat related causes of shell fracture.

The average AIS for the sample of survivable and potentially survivable accidents was 2.77. The most severe average AIS in this group was seen with rod-shaped surfaces (3.84) which accounted for 9.63 percent of this sample. The least severe occurred with the wedge-shaped surfaces (0.40) which accounted for 3.70 percent of the total. Hemisphere-shaped impactors accounted for only 2.22 percent of this sample and had an average AIS of 3.67. The average AIS with the flat surfaces was 2.76, which corresponded to 60 percent of the sample.

Most of these injuries were from blunt trauma, not from puncture of the shell by sharp objects. Increased flexural-stiffness to prevent puncture leads to increased shell weight. Consequently, the energy-attenuating foam is decreased in thickness to keep the helmet lighter. We feel that this is self-defeating. A lighter helmet shell would allow the use of thicker foam. An increase in foam thickness should lower the severity of injuries with all types of impact surfaces except for the most rigid and sharp edged ones.

The current weight limit for the SPH-4 set by Army standards is 1.56 kg (3.5 lb). This figure was not empirically derived, but based on comparison with other types of vehicular protective helmets. It was felt that this limit was reasonable for the sake of comfort and as a baseline weight which could be increased with the addition of other accouterments to the helmet (i.e., NVG, NBC ensemble, etc.). The current weight limit does not seem to pose a major problem in terms of safety or comfort and allows the use of sufficient features to make the helmet highly effective in preventing injury.

Present standards (Department of the Army, 1975) require the SPH-4 helmet to be impacted onto a hemisphere. This standard is unrealistic as only 2.22 percent of the 135 helmets involved in survivable or potentially survivable incidents received impacts from a hemispherical object. The impact of the 4.8 cm round surface against the rounded helmet results in a highly concentrated load as compared to an impact against a flat surface. The concentrated load requires a relatively thick shell to provide sufficient load distribution to prevent excessive in-bending of the shell and "bottoming" (i.e., complete compression of the foam) during impact.

The fiberglass shell of the SPH-4 accounts for approximately 35 percent of the total mass of the helmet. The shell could be be reduced to half of its current thickness and still provide adequate load-spreading if the energy-absorbing foam liner were increased in thickness by 50 percent. With such a change, Rolsten and Haley (1983) have shown that the transmitted force to the head also could be reduced by half in impacts with flat surfaces. The thicker liner would necessitate a larger shell diameter and increase the surface area by about 30 percent. However, because it would be only one-half as thick, the weight of the shell would still be 35 percent less than that of the present model. With the addition of a new, lower density foam, the total weight of such a fully assembled helmet would be 1.34 kg (3.0 lb).

In order to meet the current standard, the fiberglass helmet shell must be thick (2.5 mm) and heavy. The foam required inside the helmet also needs to be more rigid and consequently it is less effective as an energy-attenuator. The relative lack of helmet punctures in our accident data argues against the need for such a thick, heavy shell. (It should be noted that the SPH-4 specifications require no ballistic penetration protection.)

As shown in Table 9, cases with impacts to the front of the helmet had relatively mild injuries. The foam liner in this area provides good coverage, while the visor cover (and possibly the visor) provides added protection to this area. Also, the frontalis bone is the thickest and most durable part of the skull's anatomy, and trauma to this area is generally less severe than for other areas of the skull. Those cases with no discernable helmet impacts suffered injuries mostly to the face and neck.

Impacts to the side area of the helmet were responsible for more severe injuries than impacts to other areas. The lack of foam in this area (as shown in Figures 2 and 3) and the presence of the extremely rigid earcup are responsible for these severe injuries. The current rigid-plastic earcup doesn't yield on impact. A "crushable" earcup which would be able to absorb energy during impact has been developed by USAARL under United States Army Contract DABT 01-79C-0250-1. The design is based on the requirement that the acoustical protection should equal or exceed that of the existing earcup and that the crushing characteristics of the earcup should provide enhanced impact protection to the wearer's head. One such prototype earcup constructed of convoluted aluminum is compared with the present earcup in Figure 9. The specifications for the planned replacement helmet for the SPH-4, the Head Gear Unit No. 56 (HGU-56), requires the inclusion of an energy-absorbing "crushable" earcup.

Figure 10 compares the force versus time of the present earcup and the experimental convoluted aluminum earcup. The reduction of force from 22,400 N down to 5,800 N is a definite improvement and would surely contribute to injury reduction as indicated by Haley et al., 1983.

Major impacts to the rear of the helmet were associated with more severe injuries except those suffered on the sides. The low number of such impacts in this study emphasizes this severity. Future helmet designs should include larger area coverage in the rear to counter this problem.

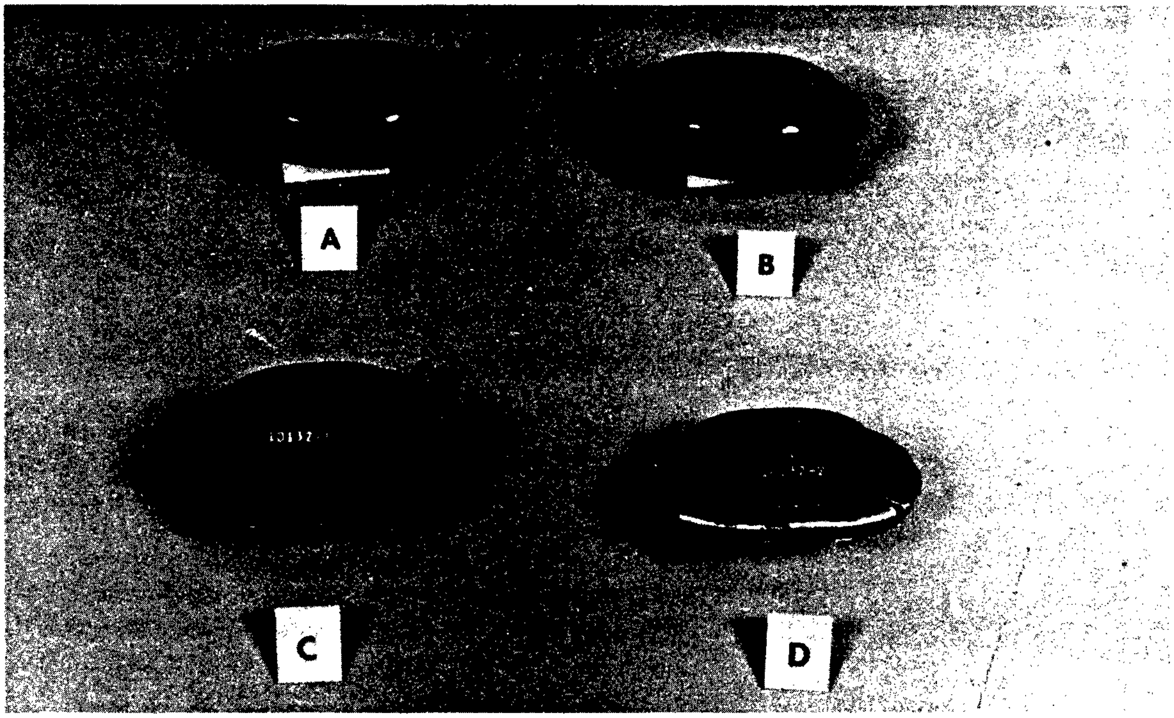

FIGURE 9. Present Earcup Pre- and Post-Impact (A and B) Experimental Earcup Pre- and Post-Impact (C and D)

A review of Table 10 shows that severe head injuries (AIS 3 or greater) are occurring with a minimum amount of residual foam compression. For example, 28 AIS 3 or higher injuries (21 percent of the total; 38 percent of the AIS 3 or higher cases) occurred with less than 20 percent foam compression. On the other hand, the foam was fully utilized (>50 percent compression) in only 11 cases (8 percent of the total), all of which were AIS 3 or greater (15 percent of the AIS 3 or higher cases). In essence, the data show that the "crushable" foam does not compress at a low enough load. We believe that the present foam liner, which crushes at a stress value of 140 psi (10 kg/cm^2), as shown in Figure 11, is five times more than needed. Note also in Figure 11 that a polyurethane foam of 44 percent the density of the present SPH-4 polystyrene foam provides much better energy absorption. USAARL experimental dynamic tests have shown it is possible to reduce the average acceleration of a helmet dropped from a 2.44m height from 150g with a standard helmet to approximately 75g with a modified helmet by the substitution of a liner 3.5 cm thick and a lower crush strength. Recommended stress-strain properties for the helmet liner also are shown in Figure 11. As discussed earlier, this liner of decreased density and increased thickness can be provided in flight helmets without significantly altering the overall helmet in size and weight. The use of compressive stress versus strain as design criteria to meet various standards is discussed in more detail by Haley et al., 1983.

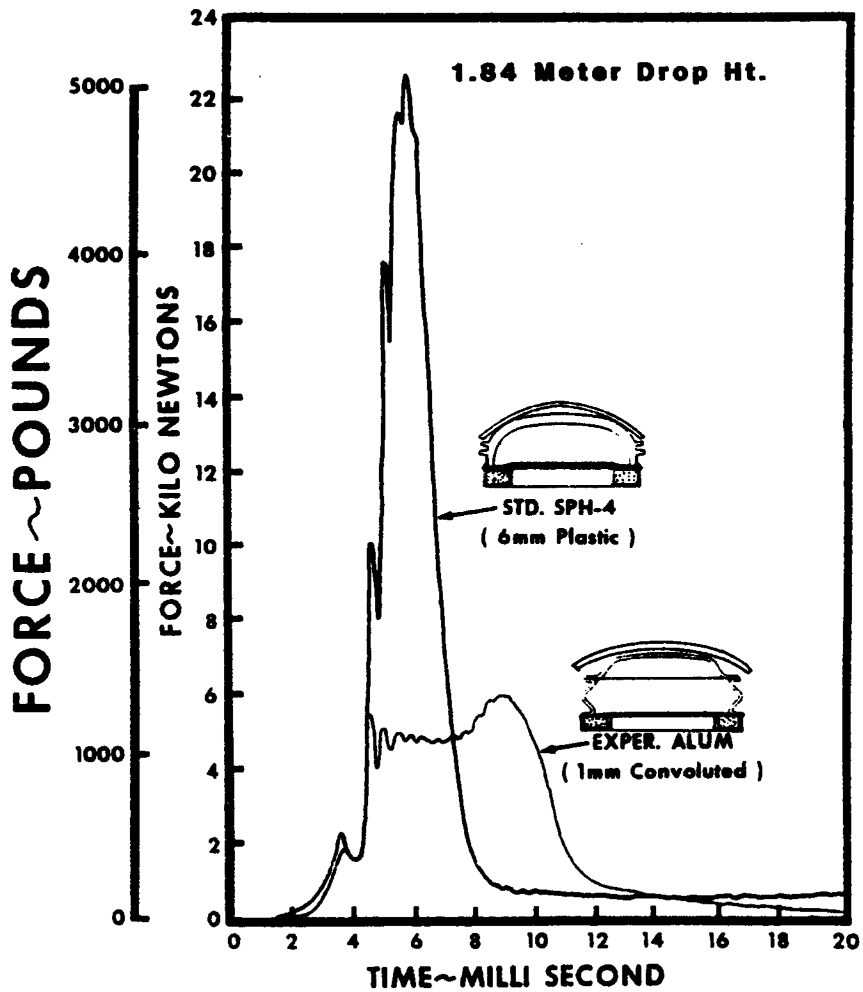

FIGURE 10. Force-Time Trace of 9.68 kg-m Drop Onto Standard and Experimental Earcup.

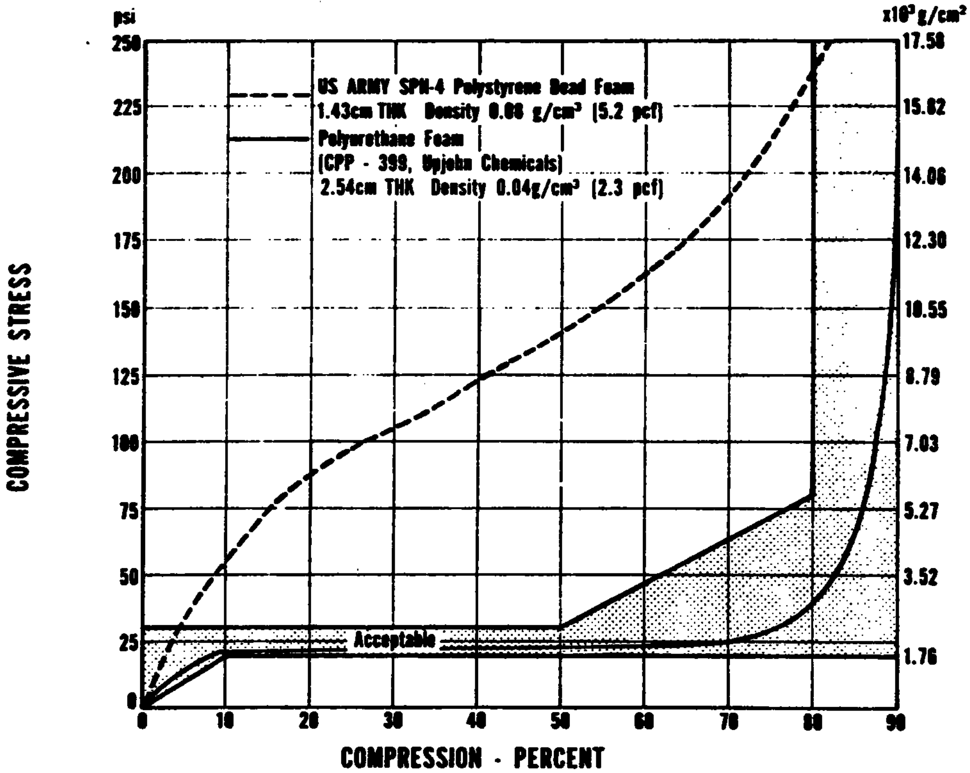

FIGURE 11. Compressive Stress-Strain Curve of Present and Experimental Foam.

CONCLUSIONS

1. Retention of the helmet by the wearer during the accident sequence was associated with a significant reduction in both the number and severity of injuries as compared to those individuals whose helmets came off.

2. The improved chinstrap systems introduced since 1978 have eliminated the chinstrap failure problem.

3. When the facial visor was utilized properly, there was a significant decrease in the percentage of fatalities and a consequent increase in survivability for the wearer during all accidents whether or not facial injuries were involved.

4. The most common impactors in peace time accidents in US Army aircraft are flat surfaces. There is a minimal threat of severe puncture damage. Current standards for puncture protection in aviation helmets make them excessively rigid, and heavy. Consequently, the energy-attenuating foam liner is less compressible and absorbs less of the impact energy than it might.

5. Impacts to the sides of the helmet are associated with higher AIS levels than any other area. This is due both to the lack of compressible foam in these areas and the rigidity of the plastic earcups.

6. Impacts to the rear of the helmet although small in number are associated with higher AIS levels than any area except the sides. This may be because the helmet tends to rotate forward during the deceleration experienced on impact if the aircraft has significant forward velocity at the time of the crash. This may permit impacts to the unprotected head at the lower edge of the energy-absorbing liner as the wearer's head and torso rebound during the crash sequence.

7. The foam used in the SPH-4 liner is not compressing at a low enough load to prevent many of the injuries we see.

RECOMMENDATIONS

In light of our conclusions, the following recommendations are made:

1. Current US Army flight helmet standards for puncture protection should be lessened to allow the use of a thinner, lighter shell and more easily crushable foam.

2. The foam liner in the helmet should be made thicker, made less dense, and should extend to cover the sides and rear as far as possible.

3. Future impact testing of the SPH-4 should use flat surfaces instead of hemispheric ones as the primary test of energy absorption.

4. An energy-absorbing earcup should be designed and deployed for the SPH-4 and such requirements should be a part of all future helmet designs.

5. The visor should be worn down at all times during flight operations except when the use of Night Vision Goggles or target acquisition equipment prohibits it.

6. Future prototypes of Night Vision Goggles and target acquisition equipment should incorporate crashworthiness and energy-attenuating features in order to compensate for the loss of visor protection.

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APPENDIX A

Aviator Protective Helmet No. 5 (APH-5) Performance

DESCRIPTION

The APH-5 was the first production US Navy helmet to utilize a polystyrene energy-absorbing foam liner. The helmet was introduced to Navy flyers in the mid-50s, and was the first official US Army aviation helmet. The APH-5 color was changed from Navy white to Army green.

Pertinent features of the APH-5 were:

a. Shell- 1.6mm thick epoxy or polyester resin and fiberglass cloth layup provided in small, medium, and large sizes.

b. Liner- Energy-absorbing 1.3 cm thick expanded polystyrene foam with density of .08 gm/cm^3.

c. Suspension- Provided by three leather-covered foam pads located at the front, crown, and rear of the helmet. Three different pad thicknesses were provided.

d. Earcups- Plastic foam type with a covered spring to provide a seal.

e. Ventilation- None provided since the pads used the "breathable space" between the foam liner and the head.

f. Visor- One single full coverage acrylic lens was used.

g. Retention- A webbing chinstrap was attached directly to the lower edge of the helmet on either side and fastened by a single snap-fastener.

The APH-5 provided impact protection about equal to that of the SPH-4 for flat surface impacts; however, the noise attenuation capability was poor in comparison with the SPH-4, which was specifically designed as a sound protection helmet. The SPH-4 had an integral earcup-retention system which was designed to give a tighter and more sound-proof seal around the ears while fixing the helmet more securely to the head using both a chinstrap in the front and a napestrap in the rear. The SPH-4 was introduced into the Army inventory in the early 1970s. The APH-5 rapidly became obsolete and was removed from active service and replaced by the SPH-4 which remains today the only authorized helmet for US Army aviation personnel.

RESULTS

There were 14 APH-5s in our records. Of these, only seven were involved in survivable or potentially survivable accidents. In Table A-1 the helmets are broken down according to the number of impacts per helmet. As in the SPH-4 data from Table 7, most of the helmets received only one major impact.

TABLE A-1
NUMBER OF IMPACTS PER HELMET (APH-5)*

NUMBER OF IMPACTS	NUMBER OF HELMETS	PERCENT OF TOTAL
None	1	14%
1	5	72%
2	1	14%
3	0	0%
TOTAL	7	100%

* Nonsurvivable cases excluded.

From Table A-2, we see that 5 (36 percent) of the total 14 APH-5s were known to have come off the wearer's head during the crash sequence. This should be compared to 43 (21 percent) of the 208 SPH-4s from Table 5. The causes for helmet loss are listed in Table A-3. Injuries were more likely to be severe if the helmet was not retained during the accident as in the SPH-4 data. This proves that the foam liner was as effective an energy-attenuator in this helmet as it was in the SPH-4.

TABLE A-2
HEAD INJURY RELATED TO HELMET RETENTION (APH-5)

HELMET STATUS	AIS CODE NONE (AIS 0)	MILD (AIS 1-2)	MODERATE (AIS 3-4)	SEVERE (AIS 5-6)	TOTAL
LOST	0 (0%)	1 (20%)	0 (0%)	4 (80%)	5 (100%)
RETAINED	3 (37.5%)	2 (25%)	0 (0%)	3 (37.5%)	8 (100%)
UNKNOWN	0 (0%)	0 (0%)	1 (100%)	0 (0%)	1 (100%)
TOTAL	3 (21.5%)	3 (21.5%)	1 (7%)	7 (50%)	14 (100%)

TABLE A-3
CAUSES OF 5 HELMET LOSSES (APH-5)*

Retention system failure	1
Chinstrap fastener failure	2
Improper wear (i.e., strap not fastened, etc.)	2

DISCUSSION

Aside from hearing protection, the APH-5 performed in a very similar manner to the SPH-4 with regard to energy attenuation but the helmet loss rate of the APH-5 was approximately twice that of the SPH-4. Unfortunately, the numbers were too small for a valid statistical comparison of the APH-5 data with the SPH-4 experience. Nevertheless, the data is reported for the sake of completeness and to demonstrate the success of the basic energy attenuation design which was later used in the SPH-4 design.

APPENDIX B

ALSERP Helmet Review Form

1. USAARL CASE No. ____________________

2. USASC CASE No. ____________________

3. AIRCRAFT TYPE ____________________

4. LAST NAME OF WEARER ____________________

5. SSN ____________________

6. WEARER'S AGE ____________________

7. HELMET TYPE ____________________

8. HELMET MANUFACTURER ____________________

9. HELMET CONTRACT No. ____________________

10. POSITION OF WEARER IN AIRCRAFT AT TIME OF IMPACT: PILOT______ COPILOT ______ PASSENGER: LEFT ______ MIDDLE ______ RIGHT ______

11. SEAT ORIENTATION (FACING): FORWARD ______ SIDE ______ REAR ______

12. WAS THIS ACCIDENT FATAL TO THE HELMET WEARER?
YES ______ NO ______

13. WERE HEAD, NECK, OR FACE INJURIES PRESENT?
YES ______ NO ______

14. DID DEATH OCCUR AS A RESULT OF HEAD, NECK, OR FACE INJURIES?
YES ______ NO ______

15. COULD AN IMPROVED HELMET HAVE LESSENED THE SEVERITY OF INJURY?
YES ______ NO ______

16. WHAT FEATURE OF IMPROVEMENT WOULD HAVE LESSENED THE SEVERITY OF INJURY?

17. LIST INJURIES: #1-

18. #2-

19. #3-

20. #4-

21. #5-

22. #6-

23. #7-

24. #8-

25. #9-

26. HEAD, NECK, FACE ABBREVIATED INJURY SCALE (AIS) ______

27. DID THE HELMET COME OFF THE WEARER'S HEAD?
YES ______ NO ______ UNKNOWN ______

28. CHIN STRAP FAILURE? YES ______ NO ______

29. RETENTION SYSTEM ATTACHMENT POINT FAILURE?
YES ______ NO ______

30. EARCUP DAMAGE? YES ______ NO ______

31. VISOR POSITION AT IMPACT?
UP ____ DOWN ____ UNKNOWN ____ N.V.G. ____

32. WAS VISOR BROKEN? YES ______ NO ______

33. LIST INJURIES CAUSED BY BROKEN VISOR: #1

34. #2

35. #3

36. #4

37. DID HELMET ROTATE AND EXPOSE HELMET TO INJURY?
YES ______ NO ______

38. CLIP DAMAGE (LOOK DOWN INTO HELMET)? -Left Front ______

39. (1=No Deformation) -Front ______

40. (2=Slight Deformation) -Right Front ______

41. (3=Moderate Deformation) -Right Rear ______

42. (4=Severe Deformation) -Rear ______

43. -Left Rear ______

44. HELMET AVAILABLE? YES ______ NO ______

IMPACT SURFACE INFORMATION:

Impact No.	Concave (1)	Flat (2)	Wedge (3)	Box Corner (4)	Hemi-sphere (5)	Rod (6)	Un-known (7)	Impact Angle (8)	Object Struck (9)
45.									
46.									
47.									
48.									
49.									

50. IMPACT LOCATION:
(IMPACT NO. & DAMAGE CODE IN APPROPRIATE BLANK)-

51. CROWN: FRONT _______ (D - DELAMINATION)

52. LEFT SIDE _______ (F - FRACTURE)

53. RIGHT SIDE _______ (P - PUNCTURE)

54. REAR _______ (MM - MATERIAL MISSING)

55. FRONT: LEFT _______ (G - GOUGE)

56. RIGHT _______ (A - SIGNIFICANT ABRASION) 4mm

57. LEFT SIDE: FRONT _______ (ND - NO DAMAGE)

58. REAR _______

59. RIGHT SIDE: FRONT _______

60. REAR _______

61. REAR: LEFT _______

62. RIGHT _______

63. PERMANENT FOAM COMPRESSION (BASED ON THICKNESS OF _____ in.)

	Impact No.	Major Axis	Minor Axis	Area	Percent Compression at Greatest Point
64.	_______	______	______	______	______________________
65.	_______	______	______	______	______________________
66.	_______	______	______	______	______________________
67.	_______	______	______	______	______________________
68.	_______	______	______	______	______________________

69. IMPACT SIMULATION POSSIBLE? YES _______ NO _______

REMARKS: